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# STUDY OF OPTICAL TECHNIQUES FOR THE AMES UNITARY WIND TUNNEL. PART 7. FINAL REPORT

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George Lee

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# **Study of Optical Techniques for the Ames Unitary Wind Tunnels**

## **Part 7. Final Report**

### Introduction

This final report is a summary of "A Study of Optical Techniques for the Ames Unitary Plan Wind Tunnels." Six optical techniques were studied: Schlieren, Light Sheet and Laser Vapor Screen, Angle of Attack, Model Deformation, Infrared Imagery, and Digital Image Processing. The study includes surveys and reviews of wind tunnel optical techniques, some conceptual designs, and recommendations for use of optical methods in the Ames Unitary Plan Wind Tunnels. Particular emphasis was placed on searching for systems developed for wind tunnel use and on commercial systems which could be readily adapted for wind tunnels. The six parts of the study have been reported as MCAT Institute reports under NASA Grant NCC2-716. This final report is to summarize the major results and recommendations.

### Schlieren

1. Status of Unitary Schlierens: The three Unitary Plan Wind Tunnels were originally built with Schlieren systems with mercury arc-lamps and four foot diameter mirrors. Due to age, many of the major components have deteriorated or are broken or missing. Replacement arc-lamps are not readily available and the film for the cameras are no longer made. Knife-edge, and optical components are worn, poorly mounted and subject to vibration. Fortunately, the mirrors are in good shape. The alignment markers in some cases are missing and lack of alignment procedures makes alignment difficult and time consuming.

It was found that there is a continuing and at times urgent need for Schlieren flow diagnostics in these tunnels. It is believed that if the Schlieren could be modernized for turnkey operation, it would be routinely used for tests.

2. Focus Schlieren: Recently, Weinstein of NASA Langley made improvements to this technique to permit fairly large systems, a few

feet diameter aperture, to be built and used in large wind tunnels. The focus Schlieren can focus on to a 2-D slice of the flow so that any given slice can be observed without interference from the rest of the flow. As a consequence, the test section windows should not affect this technique like a regular Schlieren. This may have use in the 11x11 Foot Transonic Wind Tunnel which currently has plastic windows. RAC and Aerometrics are working to develop a focus Schlieren for use in the Unitary Plan Wind Tunnels.

3. Point Diffraction Interferometer: Another new technique is the point diffraction interferometer in which a Schlieren can be easily modified by replacing the knife-edge with an appropriate aperture. The main advantage of interferometry is that quantitative data are possible. It is also more sensitive and allow better flow interpretation for some flows.

#### 4. Recommendations

Modernize the existing Schlieren systems with:

- New robust Xenon flash lamps and state-of-the-art power supplies
- New cameras: 70mm, 35mm, and video
- Image processing
- Automated alignment

#### Light Sheet and Vapor Screen

1. 11x11 Laser Vapor Screen: A laser diode light sheet vapor screen is being built for the 11x11 Foot Transonic Wind Tunnel. It is configured for flow visualization of vortices from fighter models. John Schriener of the RAC Branch and Aerometrics have been working on the project for several years and the system should be completed in 1993. The system consists of a laser diode light sheet generator mounted on a track that traverses the entire test section.

2. Tracers: Tracers are particles seeded into the flow to show the flow structures. Smoke, dyes, water vapor and many other materials have been use. For large tunnels like the Unitary, water vapor is the preferred trace material. It is non-toxic, and can be easily generated in sufficient amounts. The condensation processes

at subsonic and supersonic speeds are understood. The formation of water vapor vortex images is also understood over the speed range. The main drawback of water is that the heat of condensation affects the Mach number and static pressures sufficiently so that vapor screen images should not be taken in conjunction with force and pressure data.

One other trace material that has minimal condensation effects is propylene glycol. It is also non-toxic and can be generated in large amounts.

3. Light Source: A number of light sources have been tried in the light sheet method. The laser is the best light source. It has sufficient power and the best beam quality for generating a thin and uniform light sheet. The argon-ion laser in the 5 watt range has been used in many large wind tunnels. The lower power helium-neon laser has also been used successfully. For unsteady flows, ND:YAG and Ruby lasers can be used. The diode laser chosen for the 11x11 Foot Transonic Wind Tunnel was 8 watts. It is very compact and fit into this tunnel's space and traverse requirements. Its beam qualities are poor and required filtering and special optics to form a light sheet.

4. Light Sheet Generator: Light sheets can be generated with lenses or scanners. In principle, a cylindrical lens is sufficient. In practice, two to three lenses are required for a thin-uniform intensity light sheet. Scanners using mirrors to sweep the beam are commonly used. There is no optical degradation of the laser beam and the size and location of the light sheet can be controlled.

## 5. Recommendations

- Provide laser vapor screen systems for the 9x7 and 8x7 tunnels.
- Conduct design studies on type of laser and light sheet generator for the laser vapor screen system in the 9x7 and 8x7 tunnels.

## Angle of Attack

The Unitary Plan Wind Tunnel has recently procured two optical angle of attack measurement systems which can meet the required

accuracy of 0.01 degree. The survey also revealed other systems that are used.

1. Lateral-effect detector: Complere under NASA Ames contract has developed an angle of attack device based on lateral-effect photodiodes. The angle is determined by measurement of the displaced laser beam going through an optical flat. Detector assembly is mounted in the model while the laser and electronics are mounted outside the tunnel. The system still needs to be tested for vibration, temperature, and humidity effects. The detector is subject to stray infrared lighting.

2. Interferometer: The Boeing Co. is delivering its LAM, laser angle meter to the Unitary Plan Wind Tunnels this year. The meter is a shearing interferometer. It mounts a hologram and corner cube within the model with the laser and electronics outside of the tunnel. The main problem is any beam blockage such as tunnel fog causes the meter to lose track of the angle.

3. Other meters: The Netherlands National Aerospace Lab. has purchased the Saab Elopotos system for angle of attack. The Selspot camera system has been used by the NRC at Canada for angle measurements. NASA Langley has developed a system using lasers and linear photodiode arrays. McDonnell Aircraft Polysonic Blow-down Wind Tunnel uses an angular modulation of polarized light system. Boeing is developing a laser tracker for angle and position measurements.

#### 4. Recommendations.

- Test the Complere and Boeing LAM in the 11x11 Foot Transonic Tunnel to determine whether these systems can operate satisfactorily in a tunnel environment. This will require mounting the sensors in a suitable model, designs to mount the laser systems outside the test section, and safety consideration. Training of Ames personnel to use the systems is required.

2. If the Complere or Boeing devices do not meet the requirements, the McDonnell polarized light device should be tried.



## Model Deformation

Model deformation systems typically operate on the principle of triangulation. They can be stereo-camera systems or scanners. There are systems, including commercial systems, that can meet the model deformation requirement of 0.001 inch accuracy within a 3 foot volume at 3 to 10 foot range.

1. Stereo cameras with passive targets: The current CCD cameras with passive targets under ideal conditions can meet the accuracy requirement of 0.001 inch at a range of 6 feet. The big advantage of passive targets is no instrumentation on the model is needed. The NASA Langley stereo system is currently the best system. A commercial system from Bio-Vision of Palo Alto, CA. can measure to about 0.010 inch. With better resolution cameras and software, it can be made to meet 0.001 inch. Similarly, the Ames 40x80 stereo system requires further improvements to meet the accuracy required.

2. Stereo-cameras with active targets: These systems can satisfy the accuracy requirements. However, the expense of putting tens to hundreds of LEDs in the model is expensive. Northern Digital sells the Optotrack which is a tracker/stereo camera which can track up to 256 LEDs. It has been tested by Boeing. Accuracy of 0.0006 inch was achieved in the laboratory. However, tests in the Boeing Transonic Tunnel were marred by tunnel vibrations. NASA Langley has the SETS system for the NTF, but it is outdated. The ONERA F-1 Tunnel has the RADAC system which seems to work.

3. Scanners: These devices to measure 3-D objects are coming on the market. They operate by scanning with a laser beam or a light sheet. At close range, accuracies of 0.001 inch can be easily met. At wind tunnel range, 0.004 to 0.02 inch are typical. Commercial products from Cyberware, Cyber Optics, Digibotics, etc. are available. Cyberware seems interested in modifying their system for wind tunnel model deformation.

### 4. Recommendations

- Pursue the NASA Langley and Bio Vision stereo-cameras for possible use.

- Consider the Cyberware system and test the existing Ames unit for its accuracy.
- Follow the Boeing Optotrack work. Consider joint Boeing and Ames tests on the 11x11 Foot Transonic Wind Tunnel
- Consider model deformation for the pressure sensitive paint program.

### Infrared Imagery

Unitary purchased an Agema IR camera last year. Plans are being made to use it for the pressure paint program and for general use.

1. Boundary Layer Transition: A large amount of work has been done on boundary layer transition measurement with IR imagery. Both Quast and Brandon describe flight and wind tunnel experiments. Hall verified IR measurements with liquid crystal and hot film data. Elsenar also compared IR with hot film, pressure transducers, oil flow and liquid crystals. Both Crowder, Schmitt, and Horstmann demonstrated the ability of IR for transition in production wind tunnels. Methods to generate temperature changes in the air stream to detection transition have been demonstrated.

2. Separated Flow: Two and three dimensional separated flows have been detected with the IR camera. Bandettini measured separated flows on cones. Monte developed a Stanton number scheme for 2-D and 3-D flows. Gartenburg used aluminum foils and IR cameras to detect flow separation on airfoils.

### 3. Recommendations

- Use the Agema IR camera for boundary layer transition detection.
- Deployment of the Agema camera in the 11x11 Foot Transonic Tunnel is being done. Deployment in the other tunnels should be made.
- Use the Agema camera for temperature measurements in support of pressure sensitive paints.

## Digital Image Processing

It was found that digital image processing was required for all of the flow visualization techniques. It was used to enhance the images and to process and analyze the image data.

1. Vapor Screen: It was found that digital processing techniques were effectively used on vapor screen images of vortices. Pseudo coloring, linear contrast stretching histogram equalization, grey level slicing, filtering, edge detection were some of the techniques used.

2. Boundary Layer Transition: To enhance the IR images, averaging, histogram equalization, pseudo color and plotting of pixel intensity have been used.

3. Interferometry: Contrast enhancement, filtering, and edge detection are typically used. In addition, the analysis of fringes required measurement of fringes, ordering, numbering, zooming, patching, and image subtraction. The Unitary Plan has one of the few image processors named "FAS", Fringe Analysis System built for interferometry.

4. Pressure Sensitive Paints: Typical luminescence from the paints are low and require image enhancement. Morris at McDonnell Aircraft has used averaging, as many as 100 images of a video sequence, and then average again 5 rows of pixels to determine the luminescence. Image subtraction was used to account for camera "dark current" noise. A great deal of work is being done for image mapping to account for model distortions.

5. Particle Streak Velocimetry: Cho has applied thresholding, filtering, statistical differencing, and coordinate transformation to process images for velocity measurements. Cho also developed digital image velocimetry in which particle displacements are Fourier transformed into fringes. The fringe spacing determine the velocity flow field.

6. Turbulent Structures" Smoke flow images have been enhanced by thresholding, equalization, and addition of digitized positive and negative images to form base reliefs so that the turbulent structures can be seen.

7. Model Deformation: Targets on the model are usually enhanced and processed, e.g. centroid calculations for better accuracy. Thresholding and histogram equalization can be used for background noise reduction and for target lighting levels.

8. Current Systems: The state-of-art image processing system consists of cameras, frame grabber on a PC, software, disk storage and display devices. The real-time systems have 512x512x8 pixel resolution and operate at 30 frames per second. The still cameras have a factor of 2 to 4 higher resolution.

9. Advance Systems: The next generation system will use sensors that combine sensing and computing on the same chip. Single chip with highly integrated architecture operating at 2 billion operations per second will be available. Image compression hardware and software will be used. High speed networking will be required as will be high resolution display and storage.

#### 10. Recommendations

- Start with PC based image processors for general applications.
- Use commercial software whenever feasible.
- Study the high resolution cameras for model deformation measurements.
- Maintain the "FAS" fringe analysis processor for future applications.